Fermi National Accelerator Laboratory

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Status Report on Fermilab Experiment E-760, A Study of Charmonium Produced by Proton-Antiproton Annihilation *

The E-760 Collaboration

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Status Report on Fermilab experiment E-760, A study of Charmonium produced by proton-antiproton annihilation, presented at the KAON workshop, Vancouver, July 26,1990

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This was a status report on Fermilab experiment E-760 - an experiment to study charmonium states by resonant formation in proton-antiproton annihilation. The experiment uses antiprotons circulating in the Fermilab antiproton-accumulator as the beam and an internal hydrogen gas-jet as the target. Data taking with the full complement of apparatus started in early July 1990.

The experiment is an Italian - U.S. collaboration [1]. The "playing field" is the mass region between about 2.7 GeV/c^2 and 4.0 GeV/c^2 which corresponds to antiproton momenta from 2.8 to 7.5 GeV/c. The masses and widths of the produced states are measured with the precision and resolution of the antiproton beam energy measurement while the detector serves to provide a fast trigger, to identify the final states and to distinguish signal from background. An aspect of the present technique is that states of all allowed J^{PC} are formed directly compared to e^+e^- annihilation where only states of $J^{PC} = 1^{--}$ are made directly . This has two advantages: firstly states which are inaccessible in e^+e^- annihilation either directly or through radiative decays can be investigated and secondly states which are only accessible in e^+e^- annihilation as a result of radiative decays (e.g. the χ states) can be investigated with the precision and energy resolution of the antiproton beam.

To set a scale for the luminosity and the background rejection required, a typical cross-section for $\bar{p}p$ to charmonium is a few nanobarns, e.g $\sigma(\bar{p}p \rightarrow \chi_2)$ =2.5 nb, $\sigma(\bar{p}p \rightarrow \eta_c) = 0.5$ nb. When this is multiplied by a branching ratio to an identifiable final state (a few per cent to a few per mil) a luminosity of $10^{31}/\mathrm{cm}^2/\mathrm{sec}$. is needed to produce sufficient rate. Again, since the $\bar{p} - p$ total cross-section is about 70 millibarns, a background rejection of better than 10^6 is needed.

The first experiment to study resonant formation of charmonium thru proton - antiproton annihilation was R-704 performed at the CERN I.S.R from 1983 till the ISR was closed in 1984. With a total luminosity of 3 pb^{-1} this experiment established new values for the masses and widths of the χ_2 and χ_1 states and saw 5 events (a 2.3 sigma effect) at the putative location of the ${}^1P_1$ (the centroid of the chi-states) [2] . The present experiment was proposed and approved in 1985. As an example of the first topics to be studied in the charmonium system, states predicted by the charmonium model which have not been found include the ${}^1P_1, {}^1D_2$, and ${}^3D_2$; the η_c' needs confirmation, and the widths of the χ_2 and χ_1 need to be measured precisely.

The work required to allow the Fermilab antiproton source to operate at the required energies, to achieve a small momentum spread, $(\delta \mathrm{p}/\mathrm{p}) \approx 10^{-4}$, and to have the flexibility to scan in small energy steps as is crucial for finding and measuring the masses and widths of the charmonium states is described in the references [3]. The source was originally designed for the purpose of providing antiprotons for the Tevatron collider and to operate at a momentum of 8.9 GeV/c, the injection energy of the Fermilab main ring. Figure 1 shows the location of E-760 in the antiproton source and the location of the antiproton source in the Fermilab machine complex.

Figure 2 shows a cut through the E-760 detector [4]. This is a large acceptance (2π in azimuth and from 3° to 70° in polar angle) non-magnetic detector optimized for the identification of electromagnetic final states from charmonium decay. States, for example, which decay to $J/\psi+X$ are identified by the subsequent decay $J/\psi \to e^+e^-$; the η_c can be detected by its decay to $\gamma\gamma$.

The apparatus consists of the internal hydrogen gas-jet, a luminosity monitor, a set of tracking chambers, a pair of hodoscopes, a multi-cell cerenkov counter, a forward electromagnetic calorimeter and the central electromagnetic calorimeter made of 1280 Lead-glass Cerenkov counters arranged in a pointing geometry. Electrons are identified in the Cerenkov counters; electrons and photons are also identified and have their energies measured in the calorimeters; electron-pairs from conversions and dalitz decays are rejected on the basis of pulse-height measurements in the hodoscopes, the Cerenkov counters, and the Radial Projection Chamber. The data-acquisition system based on Smart Camac Controllers which read out in parallel to VME buffers and ACP microprocessors [5] can acquire and filter 1000 events a second with 10% dead-time.

The beam energy is found by determining the velocity of the antiprotons by measuring their revolution frequency and the orbit-length. The energy of the antiproton beam has been calibrated by observing the excitation curve of the J/ψ resonance (figure 3). Effectively, this measures the length of the orbit of the circulating beam since the orbit-frequency is measured to great precision. The energy calibration has been verified by observing the excitation curve of the ψ' resonance; a preliminary analysis shows that the observed ψ' mass agrees with the standard value to within 0.1 MeV/c^2. The reproducibility of the energy measurement, checked by comparing J/ψ excitation scans performed a week apart, appears to be good to 40 KeV. The energy spread of the beam is derived from the measured orbit frequency distribution and the value of η given by the machine parameters and is typically 0.25 MeV in the center of mass.

Beams of over 20 milliamps of antiprotons are now routinely accumulated and decelerated. The internal hydrogen gas-jet has achieved 80% of its design density of 10^{14} protons/cm^2, thus giving the experiment a peak luminosity of

$8\times10^{30}/cm^2/sec$. The beam-lifetime with the gas-jet on is presently 40 hours and the experiment runs in a mode where antiprotons are accumulated for about 24 hours, the experiment takes data for 48 hours (accumulating some 400 to 600 inverse nanobarns) and the cycle is then repeated. The initial work of the experiment is to understand in detail the systematics of the detector (efficiencies, backgrounds) and the beam (momentum spread, and energy calibration). Figure 4 shows the mass distribution of candidate J/ψ events as reconstructed in the central calorimeter using a preliminary set of calibration constants.The scanning capabilities of the antiproton source have been exercised by making measurements on the χ_1 and χ_2 states. Figure 5 shows some initial scans of these states; these early data are impressively clean and suggest that this run should be quite rewarding. If time permits before the fall shutdown, the experiment will search for the $^1P_1$ state. The program will then continue in the next part of the fixed target run scheduled to start in 1991.

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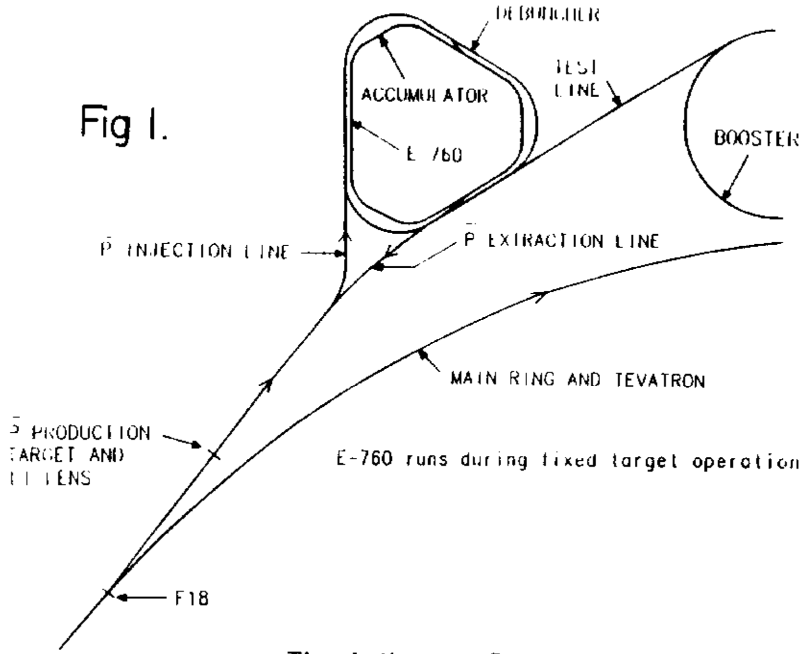
Fig 1.



The Antiproton Source

Fig 2.

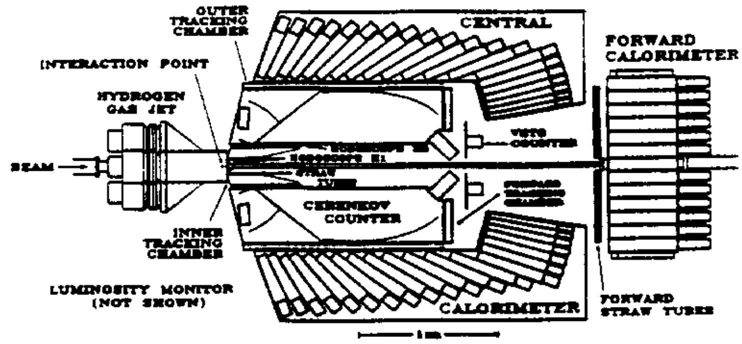


Fig 3.

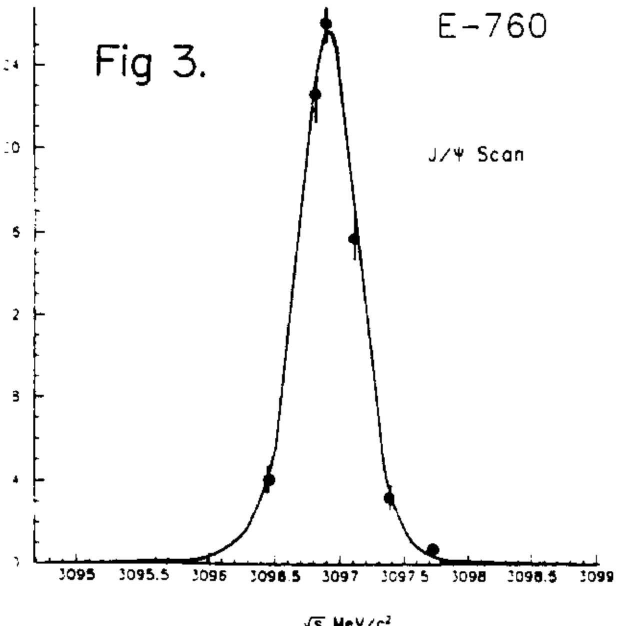


Fig 4.

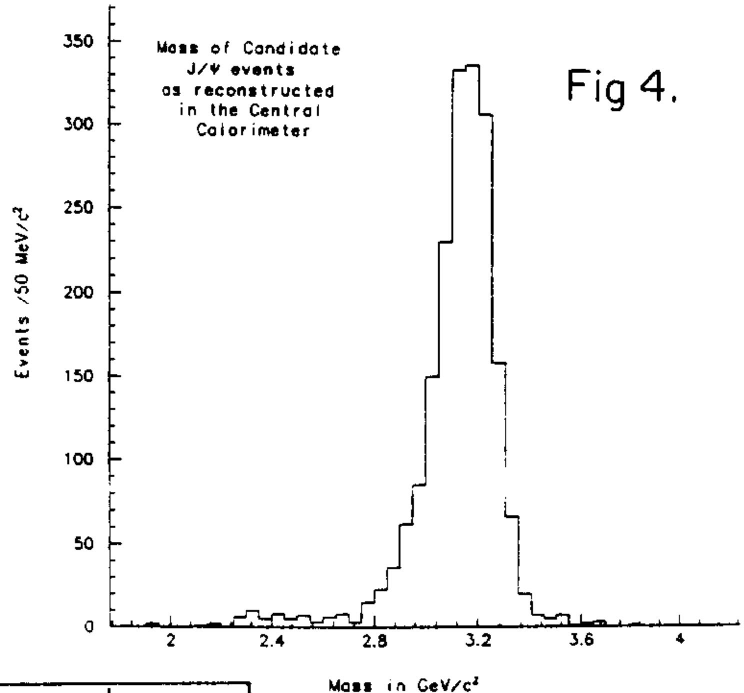


Fig 5.